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MAGNETIC FLUX LEAKAGE VERSUS ULTRASONIC CORRELATION

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Recent development in magnetic flux technology have made possible the creation of an inspection system that automatically detects and evaluates surface and subsurface defects in projectile bodies with high reliability and lower cost than competing measurement schemes. The device is capable of detecting the orientation. Operating automatically, the system can load, scan, unload, and segregate acceptable and defective parts without operator intervention. This report establishes the difference between this technique and the ultrasonic method which is currently used in production.

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INTRODUCTION

The application of the magnetic flux leakage principle for flaw detection was first developed in the 1930s and was known as magnetic particle inspection (MPI) applies a fine powder of iron particles to the surface of a magnetized body. The particles are attracted by the magnetic field gradients in the vicinity of the flaw and tend to adhere to the surface, visibly indicating the presence of flaws. Some disadvantages of the MPI method are: (1) it requires visual (subjective) inspection, (2) there is an absence of a permanent quantitative record of inspection, and (3) the method or technique capability is limited to near-surface flaw detection.

The magnetic flux leakage technique used in the automated magnetic flux leakage inspection system (AMFLIS) for detecting flaws (discontinuities) in a body "is based on the fact that a near surface discontinuity in the geometry of a magnetized body produces a local perturbation or flux leakage in the field just outside the surface of the body."* The magnitude of this flux leakage field across the discontinuity/flaw is directly related to the depth of the flaw and is not limited to near surface flaws.

The induction of flux lines into a ferromagnetic material is termed magnetization. The various types of magnetizing methods used in the AMFLIS are related to the material and tests which are conducted and are classified as follows:

1. Transverse magnetization. Flux lines enter the material from one pole in a direction normal to the surface. The lines divide equally and flow circumferentially around two segments of the body and exit normal to the surface through a second pole directly opposite the first pole. Transverse magnetization is used to detect (intersect) longitudinal discontinuities/flaws which are parallel to the body axis.

2. Longitudinal magnetization. Flux lines in the material flow parallel to the axis of the body. Longitudinal magnetization is used to detect (intersect) discontinuities which are circumferential or normal to the body axis and are called transverse discontinuities flaws.

3. Vectored magnetization. Flux lines in the material flow skewed to the axis of the body. Vectored magnetization used to detect (intersect) transverse or circumferential discontinuities can also intersect and detect longitudinal discontinuities.

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*Excerpts from Southwest Research Institute Technical Report NTIAC-80-1, January 1980

Each of the above magnetization methods can be either: active, when the magnetizing force is maintained during the test, or residual, when the magnetizing force is removed during the test.

If the body is magnetized and brought up to near saturation, both longitudinal and transverse (circumferential) discontinuities on the outside diameter (o.d.), inside diameter (i.d.), and within the walls are capable of being detected. The o.d. and i.d. defects are distinguishable by the flux leakage distribution pattern which results in a specific flaw frequency.

A flux leakage field can be detected by various types of sensors. The inductive coil sensor used by the AMFLIS is independent of temperature and supply voltage and current and is highly stable. This type of sensor is incorporated into a multiprobe design which can take on any configuration. Switching techniques enable the selection of the desired individual probe for zone identification as well as variable gain.

PURPOSE

The purpose of this test program was to compare two inspection techniques for the M42/M46 grenade body. The two techniques involved were the ultrasonic (UT) method which is currently used in production, and the magnetic flux leakage (MFL) method, the proposed alternate. The idea behind the tests was that if MFL fared as well or better than UT, then MFL would become an alternate technique to UT (or possibly a replacement for UT).

TEST DESIGN

The test plan had two main parts: the 2000 test or the 2000 data and production test or production data.

The 2000 test consisted of 2000 grenades taken from Riverbank Army Ammunition Plant production, 1000 of which had previously been accepted on one pass through UT and the 2nd 1000 of which had previously been rejected on one pass through UT. In October 1985 these 2000 serialized grenades were submitted to UT in five separate passes and the machine's decision to accept (A) or reject (R) was recorded for each pass for each grenade. The same 2000 grenades were also submitted to the MFL equipment. This same test had been attempted in March 1985 but was aborted after the 2000 grenades had passed through the UT four times but not through the MFL. The test was stopped in March and restarted in October because the standards to be used for MFL testing were not correct. In addition, 72 of the 2000 grenades were submitted to the UT and MFL devices in the manual mode which is generally considered to be more accurate than the automatic mode.

The production test consisted of approximately 10,000 grenades taken from Riverbank production and submitted to both the UT and MFL machines in accordance with the flow diagram shown in figure 1 For example, after one pass through UT, the 618 UT rejects (Ur) were resubmitted through UT and then through MFL. The 9382 grenades first accepted by UT (Ua) were then submitted to MFL, and 6390 were accepted again (UaMa) while 2480 were rejected (UaMr). After the entire test was run, 57 of the 10,000 grenades were selected for cutting and laboratory examination to determine whether each of these 57 grenades actually had a defect and what the actual flaw size was if a defect did exist.

Two other tests, involving the M77 and the M46 grenades, were also run. All tests involve the M42 grenade unless otherwise stated.

For every test that was run, standards listed below were run before, during, and after the test to confirm that the machines were not out of calibration at any point in testing. These standards were constructed to simulate flaws in grenades made by the Riverbank process. In no case was a reject standard accepted during verification tests.

MFL - begin, every 15 min., end

Prod > 1078 trials
2000 > 592 trials

UT - begin, every hour, end

Prod > 36 trials
2000 > 36 trials

OBJECTIVES

Objective 1--Determine the Percent of Product Rejected by Each Method

Using production criteria [i.e., UT rejects a grenade only upon rejecting it on two consecutive passes (UrUr), while MFL rejects on only one pass (Mr)], the following production criteria was found (fig. 2). In the 2000 test, the two machines rejected about the same amount of production: 4.9% for MFL, 5.5% for UT (October). In the production data, a great difference was observed between the two systems. UT rejected only 0.7% of the grenades while 29.2% were rejected by MFL. IT is not known exactly why such a difference occurred in production data and not in the 2000 data, but several facts are noteworthy. (1) The 2000 grenades were made of 4140 steel and tested in 1985, while the production grenades were made of the more brittle boron steel and tested in 1986. (2) The MFL inspects the embossed area of the grenade and UT does not, so there is a greater potential for the MFL to find defects. (3) Although the two systems

rejected similar quantities of grenades overall in the 2000 test, they basically did not reject the same grenades. For example, in the first 1000 grenades (i.e., the ones originally accepted on one pass by UT), the UT device rejected 8.3% (UrUr), while MFL none of these same 1000.

Objects 2--Repeatability

The overall objective here was to see which system is more repeatable and the extent to which each is repeatable. The facts below generally point out that MFL is much more repeatable than UT.

1. Two consecutive inspections on the same grenade (fig. 3).

2000 Data--When UT accepted a grenade on one pass, it accepted on a second pass 91.2% of the time, while MFL accepted 99.7% of the grenades it had accepted once already (see fig. 3).

When UT rejected on one pass, it rejected on a second pass 46.2% of the time, while MFL rejected 98.0% of the grenades it had rejected once already.

Out of the entire 2000 grenades, UT agreed with itself on two passes (either UaUa or UrUr) 85.9% of the time, while MFL agreed with itself on 99.7% of the 2000 grenades.

Production Data--When UT rejected grenades on one pass, it then rejected only 11% of those grenades on a second pass; whereas, MFL rejected 77.6% of grenades it had rejected once already. There was not enough information to compare the two systems with respect to accepting on a second pass given an acceptance on a first pass (i.e., Ua/Ua versus Ma/Ma). The percentage of time that only UT agreed with itself on two passes (either UaUa or UrUr) could be calculated, and was found to be 92.0%.

2. *With respect to M46 grenades (unembossed).*

Five hundred M46 grenade bodies which had been previously accepted by UT once were submitted to MFL three times. All three times all 500 bodies were accepted (good repeatability). They were then submitted to UT a second time; this time 55 were rejected. These 55 were entered into UT a third time and only 23 of the 55 were rejected. These 23 were submitted to UT a fourth time, and 16 of the 23 were rejected and 7 were accepted. Obviously, the UT machine had a more difficult time making repeat decisions on these M46 grenades than did the MFL machine. (This was the only test where both MFL and UT were essentially checking the same regions since the M46 grenade is nonembossed and is therefore virtually free of ID flaws which only MFL can inspect.)

3. Repeatability with respect to a particular group of 52 M42 grenades.

These grenades from the production test were rejected by UT twice and then by MFL once (i.e., UrUrMr). The 52 bodies were then submitted to MFL which rejected 50 of the 52 and accepted only 2. The 52 bodies were then submitted to UT again, and UT only rejected 38 while accepting 14. MFL repeated itself much better than UT did in this case.

4. 2000 Data--Repeatability with respect to five consecutive readings on the same 2000 grenades.

With the MFL system, 99.2% of all 2000 grenades received the same inspection decision on all five passes (either five accepts or five rejects). With the UT machine, the percentage was only 64.1% (October 1985 data). (The same 2000 grenades, when tested in March 1985, received the same answer on all five passes through UT on 96.0% of the grenades which is close to the 99.2% figure for MFL. In fact, for many of the tests in this report, the March UT data is much more similar to the October MFL data than is the October UT data to the October MFL data. In any event, however, the MFL always fared at least as well as the UT data. It is not known why UT was not able to reproduce in October the answers it gave in March. One suggested possibility is that some grenades became rusty from March to October).

5. 2000 Data--UT March versus UT October with respect to reproducibility of results from one occasion to another using all readings.

The UT system could not repeat itself very well from March to October on the same 2000 grenades. On only 1145 of the 2000 grenades (57.3%), UT was able to give the same answer of total acceptance or rejection. On 125 of the 2000 grenades (6.3%), UT extremely disagreed with itself from March to October. Again, MFL could not be evaluated for reproducibility or compared to UT because MFL was only tested in October.

6. 2000 Data--With respect to reproducibility of results from one occasion to another using two consecutive readings.

In March, UT rejected on two consecutive passes much more often than did UT in October (roughly 1000 grenades rejected on any two consecutive passes in March versus roughly 20 grenades rejected in October).

7. 2000 Data--With respect to reproducibility of results from one occasion to another using percentage of rejects per pass as the criterion.

In October, UT rejected on any typical pass about 15.8% of the first 1000 grenades while in March had only rejected 0.4% of the same grenades. On the other hand, UT rejected an average of 8% of the second 1000 grenades in October and 12% of the same grenades in March. Again the conclusion is that UT is not very reproducible, but again, UT could not be compared to MFL here since MFL was only tested in October.

8. 2000 Data--With respect to repeatability of results between automatic mode and manual mode.

Seventy-two grenades which had already passed through UT five times in automatic mode and five times through MFL in automatic mode were then passed through Ut and MFL in manual mode. In 18 out of the 72 grenades, the UT automatic mode substantially agreed with its own manual mode decision (i.e., on 18 grenades the UT automatic mode accepted on at least four of five passes and the manual mode also accepted, or UT automatic mode rejected on at least four of five passes and the manual mode also rejected). The MFL device, on the other hand, had agreement between its automatic mode and its manual mode on all 72 grenades. The conclusion is that the MFL had much more repeatability between its automatic and manual mode than did the UT. (Note: the manual mode is considered to be more accurate than the automatic mode.)

Objective 3

The overall objective here was to describe the amount of agreement/disagreement between the two systems and, whenever possible, to try to determine which system was correct upon finding a disagreement.

1. Production Data--With respect to percentage of product rejected by each machine using production criteria for rejection (i.e., two rejects for UT, one reject for MFL).

UT and MFL agreed either on acceptance or rejection of 71.2% of the product and disagreed on 28.8% of the product. Also, UT accepted 98.1% of the grenades that MDL rejected while MFL accepted only 23.5% of the grenades that were rejected by UT. UT rejected only 0.2% of the grenades accepted by MFL while MFL rejected many more (28.8%) of the grenades accepted by UT.

Now that the amount of the disagreement between the two systems has been quantified, the question then becomes which system is correct more often? Of the grenades where there was a disagreement between the two inspections systems, 29 were selected for cutting and examination (12 of the type where MFL accepted while UT rejected and 17 of the type where MFL rejected and UT accepted). It was agreed that, because of the way the standards were set, any flaw deeper than 0.035 in. should have

been detected by the MFL system and any flaw deeper than 0.045 in. should have been detected by the UT system. For example, if a flaw was determined after cutting to be 0.040 in. deep, the MFL should have called it a defect and the UT should have called it an acceptable size flaw.

Of the 12 grenades in the first category, MFL was correct 10 time (10/12 = 83.3%) while UT was correct on only two of the 12 grenades (2/12 = 16.7%).

Of the 17 grenades in the second category, MFL was correct 15 times (15/17 = 88.2%) while UT was correct only 13 times (13/17 = 76.5%). Of interest is the fact that one of these 17 had a crack that went all the way through the wall and yet was accepted by the UT (and rejected by MFL).

Although the above 29 grenades were not truly random samples, they nevertheless give some indication that MFL will give correct decisions at least as often (and probably more often) than UT.

2. 2000 Data--With respect to percent of product rejected by each machine using production criteria for rejection (2 rejects for UT, 1 reject for MFL).

MFL and UT agreed on acceptance or rejection of 89.9% of the 2000 grenades and disagreed on 10.1%. Of interest is the fact that the two systems agreed to reject only 0.3% (6 grenades) of the 2000 grenades despite the fact that each system rejected about 5% (-100 grenades) of the 2000 grenades.

3. 2000 Data--UT (October) versus MFL (October) with respect to rejects per pass.

In the first 1000 grenades (i.e., the ones previously accepted in one pass by UT) there was a great difference between MFL (0.12%) and UT (15.8%) in rejects per pass. There was no significant difference for the second 1000 (i.e., the ones previously rejected once by UT). Here MFL rejected 9.9% of grenades per pass while UT rejected 8%. UT rejected many more than MFL of the grenades that UT itself has accepted once before (fig. 4).

4. 2000 Data--With respect to agreement/disagreement between UT and MFL on multiple readings.

On 1163 of the 2000 grenades (58.1%), UT and MFL were in complete agreement to either accept or reject on all five passes through each machine. Notably, on only one grenade did both UT and MFL agree to reject on all five passes. On 103 grenades in 2000 (5.2%), the two systems completely disagreed (e.g., UT accepted five

times, MFL rejected five times). It was suggested that some of these grenades on which there was complete disagreement be cut up and examined to determine which machine was correct.

The conclusion here is that there can be a significant amount of disagreement at times between the two machines, especially where MFL has rejected grenades. It should be remembered that MFL checks the inner diameter (ID) of the embossed area while UT does not.

Objective 4--Accuracy

The overall objective was to determine which system was more often correct in its accept/reject decision making. Both alpha (rejecting good product) and beta errors (accepting defective product) were considered.

1. 2000 Data

The only information we have concerning accuracy for the 2000 data was from the manual mode inspection of 72 grenades from the 2000 which had already gone through the automatic mode of the UT and MFL machines. The assumption made was that the manual mode of either machine gives more reliable information than the automatic mode of the same machine. Seven grenades of the 72 has extremely opposite results from the UT and MFL machines in the automatic mode (i.e., UT rejected these seven grenades on all five passes while MFL accepted them on all five passes). When these same seven grenades were sent through the manual mode of both machines, all seven were accepted by the MFL machine and six of the seven were accepted by the UT machine. The conclusion, although admittedly on a small data base, is that when MFL accepts and UT rejects, MFL is correct.

2. Production Data

a. The information available regarding accuracy comes from the 57 grenades selected for cutting and examination. In fact, in the entire application test, these 57 grenades provided the only reliable information regarding the accuracy of the accept/reject decision making. Of the 57, only 47 were actually cut (the other 10 showed no indication of where to cut). Again the production criteria for acceptance/rejection for crack depth size was set at 0.045 in. for UT and 0.035 in for MFL. One concession given to UT was that it was not penalized for missing a defect in the embossed area. According to these rules, it was found that 18 of the grenades were defective (and 39 good) by UT criteria and 40 grenades were bad (and 17 good) by MFL criteria.

b. Beta error. Of the 18 grenades defective by UT criteria, 24.1% or 4.33 were accepted (partial credit was given for one grenade), while only 2 of the 40 (5%) grenades considered defective by MFL criteria were accepted by MFL; 45 of the 47 grenades actually cut had D zone flaws. At most, only one of the 47 grenades has a non-D zone flaw large enough to be called a reject. This scarcity of data in the non-D zones, especially in the A zone, which some consider to be the critical zone, limits our conclusions regarding the probability of accepting bad product to only the D zone.

c. Alpha error. It is impossible to classify a grenade as definitely good since there is no way to confirm that it contains no flaws. A grenade cannot feasibly be cut (to search for flaws) unless there is some defect indication to direct the cutting toward. So alpha error here is not an alpha error in the true sense of the word. There are few, if any good grenades in the 57 grenades, if good means flawless. All of these 57 grenades were rejected by either MFL or UT at some time or another. Also, upon examination, almost all proved to have some sort of flaw, although not every flaw was large enough to be called a defect. The 39 grenades considered good by UT and the 17 considered good by MFL therefore should not be considered as perfect but as marginally good. With that in mind, the UT rejected 26 of the 38 good grenades (66.7%) while the MFL rejected only 7 of the 17 good grenades (41.2%). Also, nine grenades were not cut at all because no indication of where to cut could be found by manual mode inspection (UT or MFL). Of these nine very good grenades, UT rejected all nine (100%) and MFL rejected only one (11.1%)

d. Production Cutups. The accuracy of the UT and MFL based on the 57 production grenades selected for cutting and examination are shown in figure 5. On the bottom scale is the true depth of the crack according to the information gleaned from the cuttings. There are three histograms marked with x's and o's signifying accept decisions and reject decisions, respectively. The figure shows what decisions the MFL made regarding ID cracks. Note that MFL rejected all ID cracks including five it should have accepted (<0.035 in.)

The middle histogram shows what decisions the MFL made regarding outer diameter (OD) cracks. Notice that it rejected one grenade of zero size crack (one of the nine grenades that was not cut because there was no indication in manual mode of where to cut), and it rejected two other grenades with cracks less than 0.035 in. depth.

The top histogram shows the decisions made by the UT regarding OD cracks. Notice the almost of random spread of x's and o's, including one accept at 0.100 inch and nine rejects at zero size crack.

The conclusion is that MFL has smaller beta and alpha errors.

Objective 5

To determine if the ID inspection capability of the MFL is actually necessary or even useful. In other words, are the ID cracks detected by MFL of critical size or is the MFL system causing many nuisance rejections?

Size of ID Cracks

Of the 57 grenades (production data) selected for cutting, 37 had ID cracks. Of these 37, 32 had ID cracks greater than 0.035 in and five less than 0.035 in. (note also that 17 of these 32 also had OD cracks greater than 0.035 in.). The grenade standard for the MFL was set at 0.040 because it was determined that this was the size above which trouble could be caused and should be detected. When the MFL machine was tested, it was set up to reject any crack greater than approximately 0.035 in. in order to assure that it would reject any crack greater than 0.040 in. (fig. 6). Therefore, of the ID cracks found, most were of a size deemed to be significant.

Percent of ID Cracks in Total Production

Since there was no direct was of quantifying the percent of significant sized ID cracks in total production, it was estimated using three different techniques.

1. Cutups

On the first pass, 45 of the 57 were rejected by MFL. Of these, 32 had ID cracks greater than or equal to 0.035 in. (32/45 = 71.1%). Of the 9485 production grenades, 2786 (29.4%) were rejected by MFL on the first pass (71.1% x 29.4% = approximately 20.8%). Therefore, one estimate of percent of ID cracks in production is 20.8%. It should be noted, that the 57 selected for cutup were not random samples from the population of 2786 MFL rejects. Therefore, the 20.8% should be considered a crude estimate.

2. Desensitized Prove (zone D)

The 186 MFL rejects were resubmitted to MFL with the ID probe desensitized on this second pass. This time only 44 of the 186 were rejected. (It was assumed that the other 142 were rejected on the first pass for ID cracks (142/186 = 76.3%).

On one pass, 2768/9485 equaling 29.4% were rejected by MFL. 76.3% x 29.4% equals approximately 22.3%. Therefore, by this estimation method, about 22.3% of production grenades had ID cracks rejectable by the MFL inner probe at zone D.

3. M46 (non-embossed) Grenades

Five hundred M46 grenades accepted by UT were used in this test. Since embossing is what creates most of th e ID cracks and the M46 is non-embossed, there would be little chance of an ID crack in these grenades. These grenades were submitted to MFL three times. All 500 were accepted each time (0/500 = 0%). With the M42 grenade, on the other hand, 28% of the UT accepted grenades were rejected by MFL. Therefore, most of these 28% rejects must have been for ID defects, since 0% of the M46 grenades were rejected when the potential for ID cracks was eliminated.

4. Conclusion

Based on the aboe three methods, it is estimated that at least 20% of M42 grenades have an ID crack of substantial size (greater than 0.035 in. in most cases). Therefore, if it is believed that a grenade with an ID crack depth of at least 0.035 in. should be removed, then the MFL is necessary because UT has no ID defect capability in the embossed area.

CONCLUSIONS

Probability of Rejection

Magnetic flux leakage (MFL) and ultrasonic (UT) rejected about the same amount of product of the 2000 data but MFL rejected more of the production data.

Repeatability

MFL was more reapeatable from pass to pass on the same grenade and was more repeatable from automatic mode to manual mode than UT.

Agreements/Disagreements

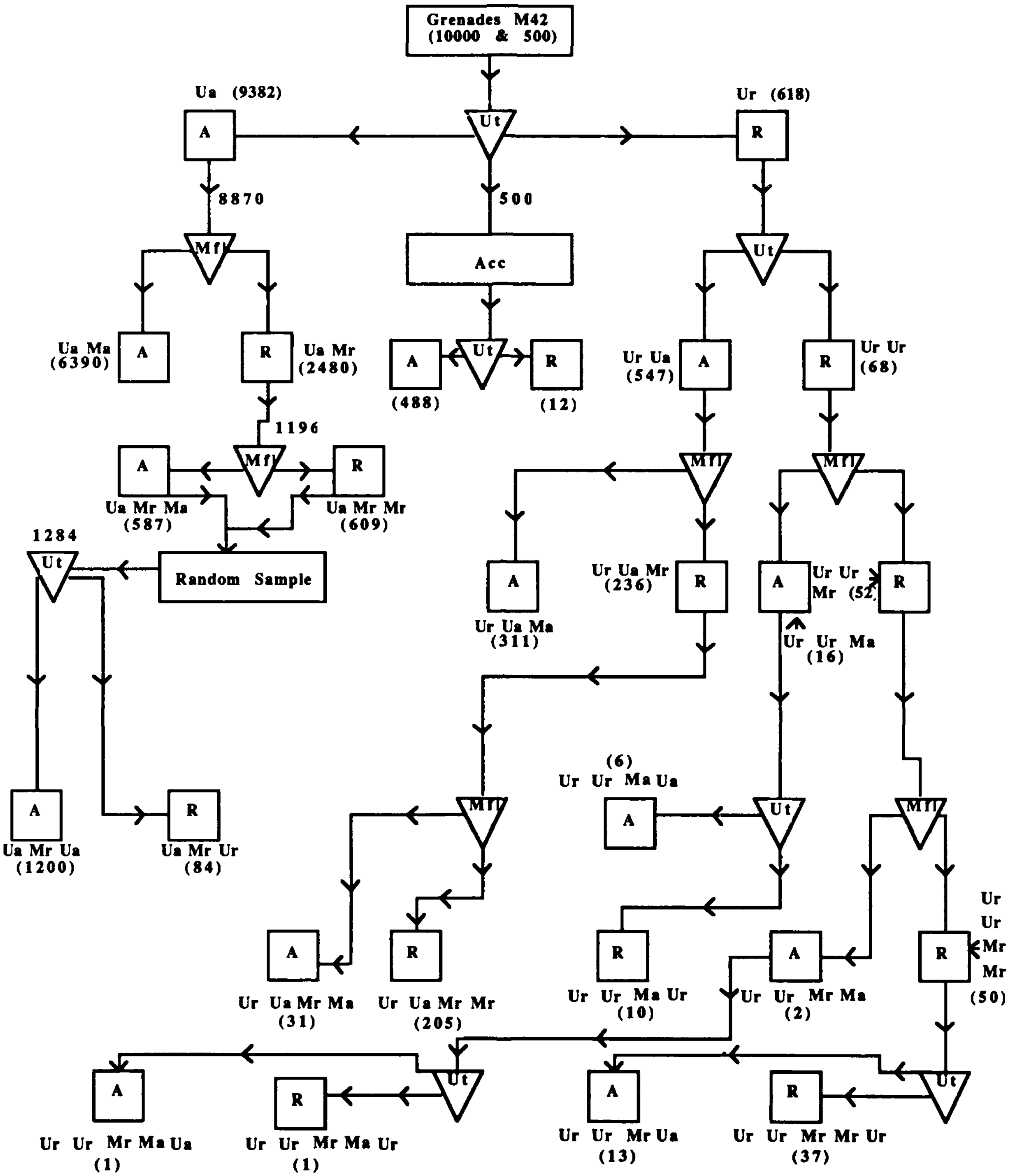
MFL and UT agreed to accept or reject 90% of the 2000 grenades, but agreed on only 71% of the production grenades.

Accruacy

MFL was better than UT with respect to accurach since it had a smaller alpha error (41% versus 67%) and a smaller beta error (5% versus 24%). The beta error is the more serious one since it involves accepting grenades with flaws.

ID Cracks

Many inner diameter (ID) cracks exist in production grenades and many of these cracks are large. The MFL inspection method has the capability of detecting cracks in the embossed ID area while the UT inspection method has no capability here. It is not known at this time what size crack is critical, but what is known is that cracks do not improve; they can only get worse due to handling, environments, aging, etc. A good argument can therefore be made for not being liberal in the acceptance of ID cracks. Note also that the sensitivity level for rejection on MFL can be raised, lowered, or eliminated if so desired.



Legend :

Ut - Ultrasonic Test R - Reject Ma - Magnetic Flux Accept
Mfl - Magnetic Flux Analisys Ur - Ultrasonic Reject Mr - Magnetic Flux Reject
A - Accept Ua - Ultrasonic Accept

Figure 1. Production test

- 2000 (OCT)

P(UA) = 94.5%
1ST - 91.7%
2ND - 97.4%

P(UR) = 5.5%
1ST - 8.3%
2ND - 2.6%

P(MA) = 95.1%
1ST - 100%
2ND - 90.2%

P(MR) = 4.9%
1ST - 0.0%
2ND - 9.8%

- PRODUCTION

P(UA) = 99.3%
P(MA) = 70.8%

P(UR) = 0.7%
P(MR) = 29.2%

Figure 2. Probability of acceptance/rejection, production criteria

- 2000 OCT

	1ST 1000	2ND 1000	TOT
P(UA/UA) =	87.6%	89.1%	88.4%
P(MA/MA) =	99.8%	99.7%	99.7%

	1ST 1000	2ND 1000	TOT
P(UR/UR) =	54.6%	31.0%	46.2%
P(MR/MR) =	N/A	98.0%	98.0%

- PRODUCTION

P(UA/UA) = 97.6%

P(MA/MA) = N/A

P(UR/UR) = 11.0%

P(MR/MR) = 77.6%

- **M46 GRENADES (UNEMBOSED)**

500 GRENADES ACCEPTED ONCE BY UT

ALL 500 ACCEPTED 3 TIMES BY MFL

BUT, UT = 55, UR/UR =23, UR/(UR UR) =16

CONCLUSION: MFL REPEATS MUCH BETTER THAN UT (ON BOTH, ACCEPTS & REJECT S)

Figure 3. Repeatability, one pass criteria

AGREEMENTS / DISAGREEMENTS

2000 - UT VS. MFL (OCTOBER)

REJECTS PER PASS

	1ST 1000 (PREVIOUSLY ACCEPTED)	2ND 1000 (PREVIOUSLY REJECTED)	TOTAL
MFL OCT.	0.12%	9.9%	5.0%
UT OCT.	15.82% (9.9%)*	8.0%	11.9% (8.8%)*

CONCLUSION : UT REJECTS MUCH MORE OF THE GRENADES THAT IT HAD PREVIOUSLY ACCEPTED THAN MFL REJECTS

*** EXCLUDING 1ST 200 GRENADES**

Figure 4. Agreements/disagreements

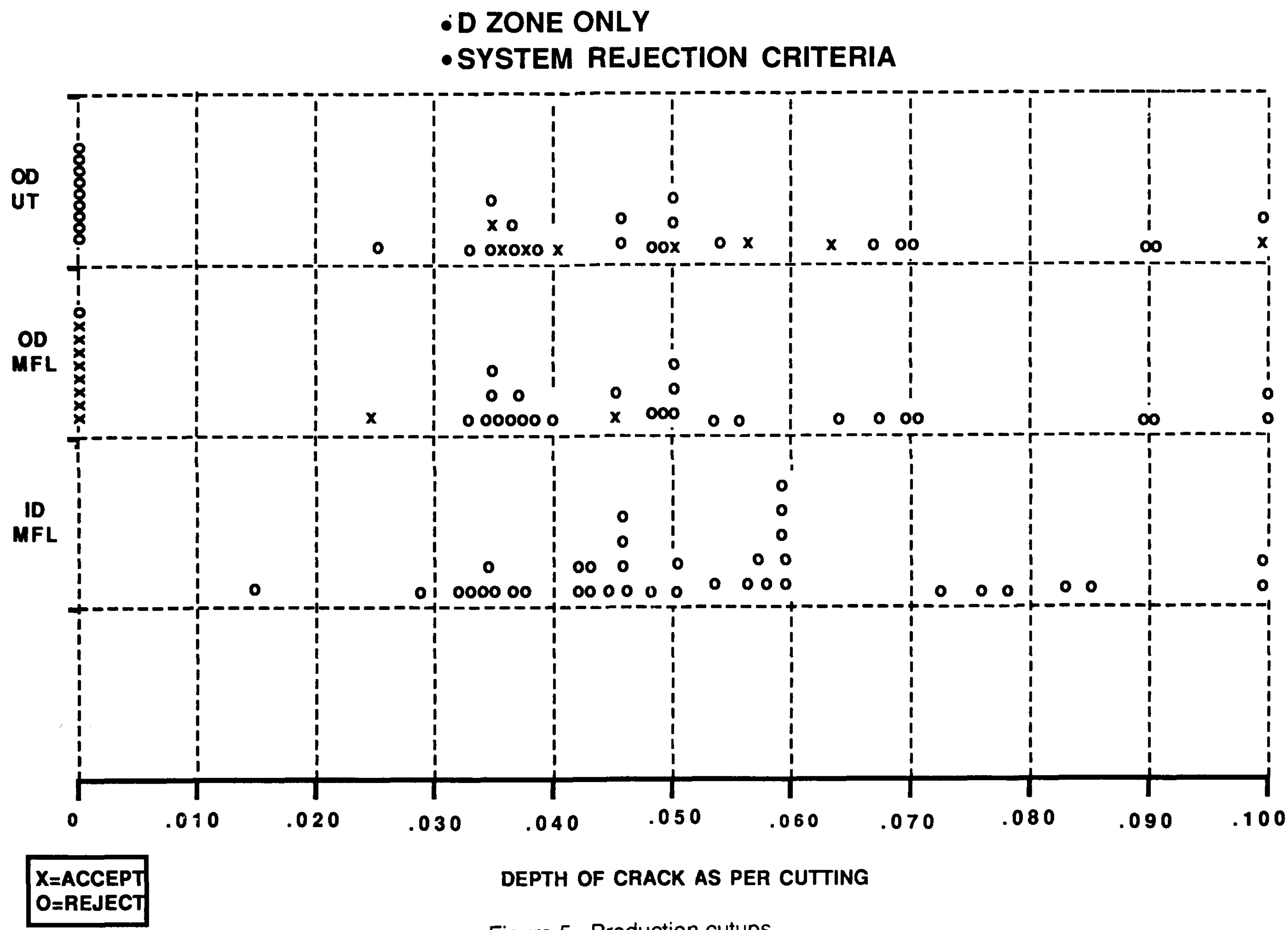


Figure 5. Production cutups

- SIZE OF ID CRACKS
  - OF THE 57 SELECTED FOR CUTUP, 37 HAD ID CRACKS
  - OF THE 37 , 32 HAD ID CRACKS ≥ .035"

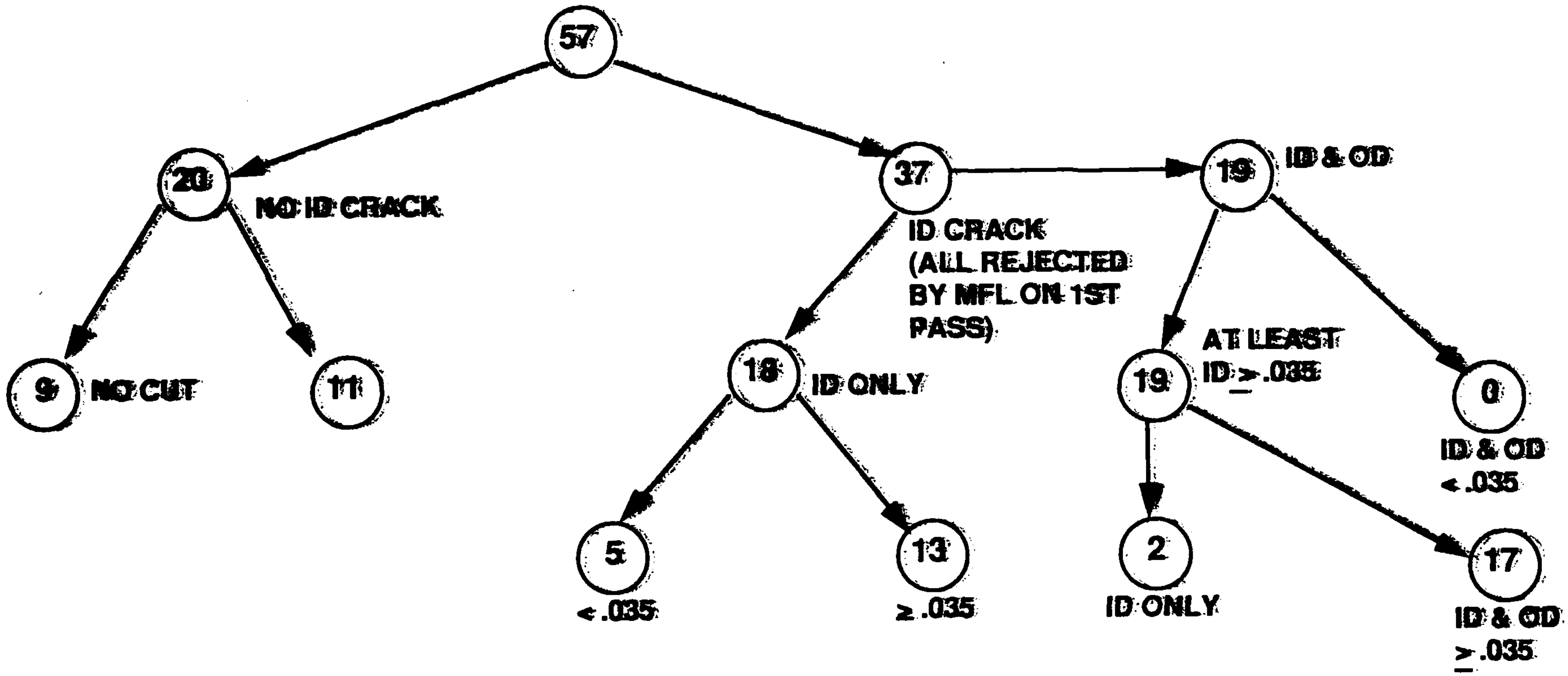


Figure 6. Inside and outside diameter using production data

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